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Aerosol Optical Depth Changes in Version 4 CALIPSO Level 2 Product

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Introduction

- The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) version 4.10 (V4) products were released in November 2016 with substantial enhancements.
- There have been improvements in the V4 CALIOP level 2 aerosol optical depth (AOD) compared to V3 (version 3) due to various factors. AOD change from V3 to V4 is investigated by separating factors.
- CALIOP AOD was compared with the Moderate Resolution Imaging Spectroradiometer (MODIS) and Aerosol Robotic Network (AERONET) for both V3 and V4.

V4 Algorithm Updates

- The most significant algorithm updates in V4 aerosol classification and lidar ratio selection algorithm are as follows.
  - All aerosol subtypes are allowed over snow, ice, and tundra surfaces, whereas only clean continental and polluted continental aerosols allowed in previous versions.
  - A new aerosol subtype, dusty marine, has been introduced. Polluted dust aerosols with layer base lower than 2.5 km in previous versions are now classified as dusty marine.
  - Polluted continental and smoke are revised as “polluted dust/smoke” and “elevated smoke” in V4.
  - A new scheme, the Subtype Coalescence Algorithm for AeRosol Fringes (SCAARF), is applied to re-classify the aerosol subtype of these lower fringes to the dominant subtype of the adjacent overlying layers.
  - Stratospheric aerosol subtypes have been introduced for ash, sulfate/other, smoke and polar stratospheric aerosol.
  - Aerosol lidar ratios have changed for clean marine, dust, clean continental, and elevated smoke.
- Other V4 updates that can impact on the CALIOP AOD.
  - The CALIOP V4 level 1 data significantly improved the calibration of the CALIOP attenuated backscatter coefficient at both 532 nm and 1064 nm.
  - The V4 CAD algorithm features entirely new probability distribution functions (PDFs) that are now more sensitive to the presence of lofted aerosols.
  - the V4 analyses use a completely new algorithm to detect the Earth’s surface detection.
- A special issue for the CALIOP V4 algorithm updates will be published in *the Atmospheric Measurements and Techniques*.

Feature Type and Aerosol Subtype Changes

- The feature type changes from/to aerosol, aerosol subtypes changes between V3 and V4 are analyzed using the atmospheric volume description (AVD) reported in level 2 aerosol profile product.

Table 1. Feature type and aerosol subtype changes in the CALIOP level 2 AVD between V3 and V4 from 2007 to 2009. Each (i,j) component of the Table represents what fraction (expressed as a percentage) of type i in V3 changes to type j in V4. Since the total number of each type is different, relative total amounts for each type are shown as normalized total for both columns and rows which are normalized to total number of bins for V3 aerosol.

V4 \ V3	Clear	Cloud	Surface	**Aerosol**	CM*	Dust	PC*	CC*	PD*	Smoke	**Strato. Feature**	**Normalized Total**
Clear	95.47	2.34	1.65	**6.75**	4.86	5.51	9.48	15.50	7.55	9.42	**4.10**	21.33
Cloud	0.75	92.85	1.76	**7.88**	6.61	4.98	10.90	12.34	8.57	14.46	**61.43**	2.36
Surface	2.88	0.34	93.30	**0.53**	0.19	0.82	0.89	0.66	0.67	0.62	**-**	1.12
Tropo. Aerosol	**0.79**	**4.29**	**3.29**	**84.27**	88.34	88.69	78.66	66.01	83.14	71.80	**0.31**	1.13
CM*	0.17	0.69	2.33	33.47	79.05	0.43	21.42	12.15	6.28	0.13	-	0.40
Dust	0.16	1.70	0.20	16.95	0.25	72.16	1.78	5.29	6.67	0.99	0.10	0.24
PC*/Smoke	0.06	0.24	0.18	5.63	0.93	0.49	31.99	10.24	5.19	18.68	-	0.08
CC*	0.03	0.02	0.02	0.62	0.00	0.05	0.57	8.68	0.52	0.66	0.02	0.01
PD*	0.16	0.85	0.15	10.61	0.03	10.34	5.43	11.69	31.41	7.29	0.07	0.16
Elev. Smoke	0.12	0.44	0.02	7.34	4.04	0.29	11.30	10.28	4.67	43.51	0.12	0.11
DM*	0.09	0.35	0.38	9.67	4.05	4.94	6.16	7.68	28.40	0.54	-	0.13
Strato. Aerosol	**0.12**	**0.18**	**-**	**0.57**	0.00	0.01	0.07	5.49	0.07	3.69	**34.15**	0.07
PSC Aerosol	0.02	0.07	-	0.03	-	-	0.00	0.64	0.00	0.00	13.79	0.02
Volcanic Ash	0.00	0.01	-	0.00	-	0.00	-	0.00	0.00	0.00	0.24	0.00
Sulfate/other	0.10	0.10	-	0.54	0.00	0.00	0.07	4.83	0.07	3.67	19.91	0.05
Smoke	0.00	0.01	-	0.00	-	-	0.00	0.02	0.00	0.01	0.21	0.00
Total	100	100	100	100	100	100	100	100	100	100	100	
Normalized Total	22.20	2.21	0.50	1.00	0.38	0.21	0.06	0.05	0.22	0.08	0.09	

* CM=clean marine, PC=polluted continental, CC=clean continental, PD=polluted dust, DM=dusty marine.

AOD Changes from V3 to V4

- We categorized these factors as changes in layer detection, cloud-aerosol discrimination (CAD), surface detection, stratospheric aerosol, aerosol type, and lidar ratio using feature type and aerosol subtype in level 2 atmospheric volume description (AVD) data.

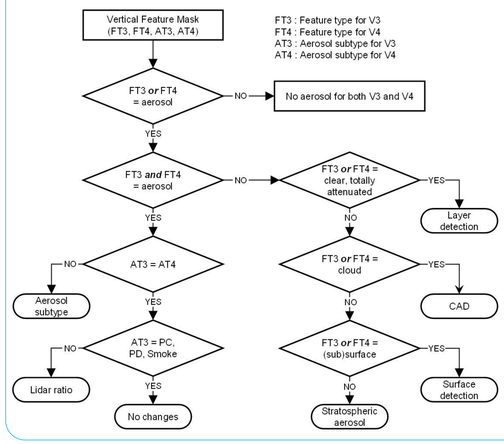

Table 2. Global mean AOD changes from CALIOP V3 to V4 and their bin frequencies for different factors described in Figure 1 from 2007 to 2009.

	Frequency (%)		AOD change	
	Day	Night	Day	Night
Layer detection	18.2	22.4	0.011±0.133	0.027±0.164
CAD	12.4	13.2	0.018±0.179	0.015±0.249
Surface detection	1.4	1.4	0.003±0.027	0.001±0.052
Stratospheric aerosol	3.4	4.9	0.001±0.016	0.001±0.020
Aerosol subtype	18.6	17.3	-0.002±0.115	0.009±0.148
Lidar ratio	36.2	29.8	0.016±0.105	0.017±0.112
No change	9.8	11.0	0.004±0.070	0.005±0.085
Total	100	100	0.051±0.296	0.075±0.383

←*Figure 1. Flowchart to categorize factors that impact on the AOD change between V3 and V4.*

Initial Validation with AERONET and MODIS

- CALIOP AODs for both V3 and V4 are compared with AERONET (±30 min, 40 km in radius) and MODIS (CALIOP AODs closer than 10 km from the center of MODIS pixel) from 2007 to 2009.

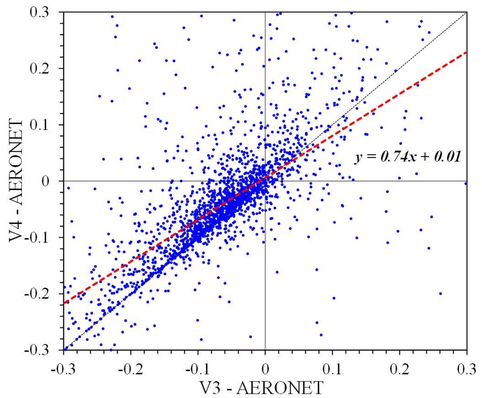

Figure 2. Scatter plot for V3 CALIOP AOD difference from AERONET versus V4 CALIOP AOD difference from 2007 to 2009.

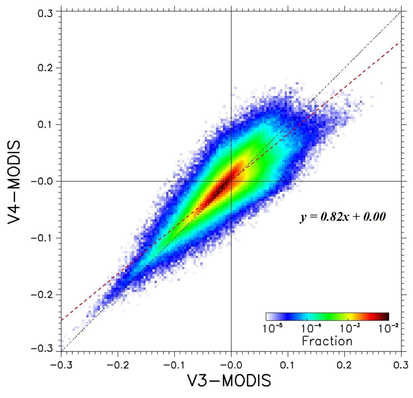

Figure 3. Distribution of V3 CALIOP AOD difference from MODIS versus V4 CALIOP AOD difference over ocean from 2007 to 2009.

Table 3. Mean (± standard deviation) and median (± median absolute deviation) of AOD difference between CALIOP and AERONET/MODIS for V3 and V4 from 2007 to 2009.

	CALIOP V3		CALIOP V4		Number of
	mean	median	mean	median	data pairs
AERONET	-0.071±0.207	-0.057±0.044	-0.023±0.233	-0.043±0.045	2,699
MODIS (Ocean)	-0.012±0.079	-0.015±0.025	-0.008±0.067	-0.010±0.024	1,018,324
MODIS (Land)	0.061±0.206	0.050±0.089	0.106±0.223	0.074±0.094	49,632

Summary

- Aerosols have increased by 13% in V4 compared to V3, which implies that the V4 algorithm detects weakly scattering layers that are subsequently classified as aerosols.
- As a result of this increase in the number of aerosol layers, the number of most aerosol subtypes also increases. The sole exceptions are polluted dust and clean continental.
- The CALIOP level 2 global mean column integrated AOD at 532 nm has increased by 0.051 for daytime and 0.075 for nighttime in V4 from 2007 to 2009.
- Categorization of factors for AOD changes between V3 and V4 shows that the most significant reasons for AOD increase in V4 are changes in aerosol layer detection, CAD and lidar ratio.
- Comparison of AERONET and MODIS with both version of CALIOP shows that mean AOD differences with AERONET and MODIS (ocean) are reduced in V4 compared to V3.

AOD Changes (V4 – V3)

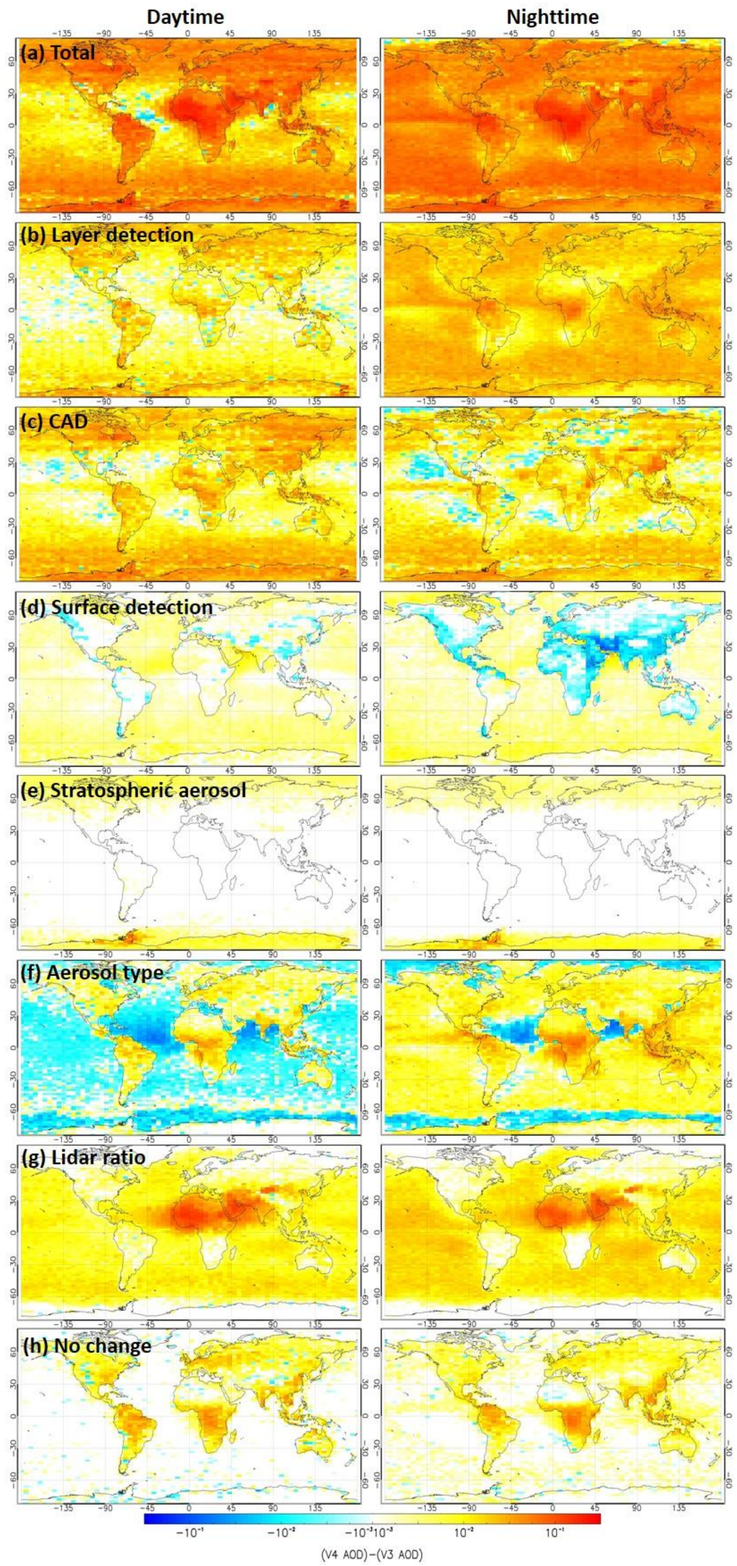

Figure 4. Global maps of mean AOD differences between V3 and V4 for each factor categorized in Figure 1 from 2007 to 2009; (a) total, (b) layer detection, (c) CAD, (d) surface detection, (e) stratospheric aerosol, (f) aerosol subtype, (g) lidar ratio, and (h) no changes. Left and right columns are for daytime and nighttime, respectively.